# Age-related changes in motor subtle signs among girls and boys with ADHD

W.R. Cole, PhD
S.H. Mostofsky, MD
J.C. Gidley Larson, MA
M.B. Denckla, MD
E.M. Mahone, PhD

Address correspondence and reprint requests to Dr. E. Mark Mahone, Department of Neuropsychology, 1750 East Fairmount Avenue, Baltimore, MD 21231
mahone@kennedykrieger.org

## ABSTRACT

**Objective:** To examine differences in age-related improvement in motor speed and neurologic subtle signs (overflow and dysrhythmia) among boys and girls with and without attention-deficit hyperactivity disorder (ADHD).

**Method:** Diagnosis of ADHD was determined by structured parent interview and administration of ADHD-specific and broad behavior rating scales. Motor function was assessed using the revised Physical and Neurological Assessment of Subtle Signs. Three primary outcome variables were obtained: 1) total time, 2) total overflow, and 3) total dysrhythmia. Effects of age, group, and sex were assessed.

**Results:** Both control and ADHD groups showed improvement on timed tasks with age; however, controls were consistently faster across the age span. Controls and girls with ADHD showed steady age-related reduction of overflow and dysrhythmia, whereas boys with ADHD had little improvement in these signs through age 14 years.

**Conclusion:** Results indicated that girls with attention-deficit hyperactivity disorder (ADHD) performed similarly to age-matched controls on a quantified motor examination. These results parallel patterns of findings from neuroimaging studies, in which neurologic anomalies in areas related to motor control are present in boys with ADHD, but more equivocal in girls with ADHD. Sex-related differences observed in children with ADHD likely extend beyond symptom presentation to development of motor control, and are likely related to earlier brain maturation in girls.
***Neurology*® 2008;71:1514–1520**

## GLOSSARY

**ADHD** = attention-deficit hyperactivity disorder; **CPRS** = Conners' Parent Rating Scale; **DICA** = Diagnostic Interview for Children and Adolescents; **DSM** = Diagnostic and Statistical Manual of Mental Disorders; **WISC** = Wechsler Intelligence Scale for Children.

Neuroanatomic structures involved in voluntary control of motor skills show substantial growth, elaboration, and myelination during early childhood.[1] Developmental changes in motor control include improvements in speed as well as reduced frequency of "subtle signs," such as overflow and dysrhythmia. Motor overflow refers to presence of involuntary movements that accompany the production of voluntary movements,[2] and has been linked to impaired inhibitory control.[3] Dysrhythmia involves improper timing or rhythm during controlled movements.

While it is common to observe subtle signs in typically developing children younger than age 10,[4] most basic motor skills are mastered by age 6 or 7,[5] and persistence of subtle signs into late childhood and adolescence can indicate atypical neurologic development.[6,7] The majority of studies examining atypical motor development in attention-deficit hyperactivity disorder (ADHD) have included predominantly male samples, with fewer studies exploring whether similar patterns emerge among girls with ADHD. Studies examining motor skills in typically developing children have shown sex-specific patterns, with girls maturing

From the Kennedy Krieger Institute (W.R.C., S.H.M., J.C.G.L., M.B.D., E.M.M.), Baltimore; Johns Hopkins University School of Medicine (W.R.C., S.H.M., M.B.D., E.M.M.), Baltimore, MD; and University of Utah (J.C.G.L.), Salt Lake City.
Supported by HD-24061 (Mental Retardation and Developmental Disabilities Research Center), R01 NS050153, NS 35359, R01 NS043480, K08 NS02039, K02 NS044850, R01 NS047781, M01 RR00052 (Johns Hopkins General Clinical Research Center).

*Disclosure:* The authors report no disclosures.

earlier than boys,[8] a finding consistent with trajectories of brain development identified via neuroimaging.[9]

The purpose of this study was to examine differences in age-related changes in motor speed and subtle signs in boys and girls with and without ADHD. While typically developing children were hypothesized to show improvement with age in motor skills, children with ADHD were hypothesized to show fewer age-related improvements. Further, the inclusion of both boys and girls with ADHD in this study allows us to determine if sex-specific differences observed in brain development are also present within ADHD.

## METHOD

**Participants.** Approval was granted for this study by the Johns Hopkins Medicine Institutional Review Board. Informed consent to participate was obtained from the legal guardian of 268 children (184 boys), ages 7–15. All participants were recruited from the community as part of research projects investigating brain mechanisms in ADHD at the Kennedy Krieger Institute from 1992 to 2006 and were included in the current study if they met inclusion criteria. Two groups were formed: typically developing controls (n = 136) and ADHD (n = 132). Children were included if they were free from seizures, head injury, or other neurologic illness by history. All participants had IQ of 80 or above (range 81–145), using the version of the Wechsler Intelligence Scales current at the time of testing (23 Wechsler Intelligence Scale for Children [WISC]–Revised, 102 WISC-III, 133 WISC-IV). The sample was also screened for reading disability, defined as a basic reading score less than 80, using the test current at the time. The sample was drawn from largely middle social economic status, and was predominantly Caucasian (94%). Demographic information is listed in table 1.

Children with ADHD were recruited from outpatient clinics, local pediatricians, Children and Adults with Attention-Deficit Hyperactivity Disorder groups, schools, and advertisements. All evaluations were conducted by research personnel (psychologist or psychometrician) trained to administer psychiatric interviews and parent questionnaires. Diagnosis of ADHD was determined by the Diagnostic Interview for Children and Adolescents (DICA-R; DICA-IV)[10] that utilized *DSM-III-R* criteria for children tested prior to 1995 or *DSM-IV* criteria for children tested 1995 and beyond, as well ADHD-specific (i.e., ADHD Rating Scale)[11] and broad behavior (Conners' Parent Rating Scale-Revised [CPRS])[12] rating scales.

Children with *DSM* diagnoses other than oppositional defiant disorder and simple/specific phobias were excluded. Those with ADHD were excluded if they were taking non-stimulant longer-acting psychoactive medications. Parents of children with ADHD taking stimulants were asked not to administer the medication the day of and the day prior to testing. Controls were contemporaneously recruited through the local schools and flyers posted in the community, and were required to have no history of mental health services for behavior or emotional problems, no diagnosis on the DICA, and no clinically significant elevation on ADHD Rating Scale or CPRS.

**Motor assessment.** Motor function was assessed by a neurologist, psychologist, or psychometrician trained to reliability criteria using the PANESS.[13] Examiners were blind to the child's diagnostic status at the time of assessment and during scoring. The PANESS was originally developed and normed in the 1970s[14] on 168 predominantly white, middle class, elementary age children with an average IQ. Since that time, the PANESS has been found to have adequate test-retest reliability,[15] inter-rater reliability, internal consistency,[16] and sensitivity to age-related changes[5,8] in more current and diverse cohorts. The PANESS measures salient components of motor function, including lateral preference, gaits, balance, motor persistence, coordination, overflow, dysrhythmia, and timed movements. Detailed administration[5,13] and scoring procedures[5] for the PANESS have been previously published. Three primary outcome variables were used in the current study:

Total speed of timed movements of the hands/feet was measured from six sets of timed activities, including toe-tapping, alternating heel-toe tapping, repetitive hand patting, hand pronation-supination, repetitive finger tapping, and finger sequencing, each performed bilaterally. For timed movements, the child is instructed to "Do all of these movements as quickly as you can, and as best as you can."

Total overflow included the total number of abnormal-for-age movements observed during stressed gaits (i.e., walking on heels, toes, or sides of feet), tandem gaits (walking in tandem forward and backward, touching heel to toes), as well as during timed movements. For gaits, the examiner observes for "foot-to-hand overflow," which involves flexion of hand and

**Table 1** Demographic and motor assessment results

| | Controls | | | | | | ADHD | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boys (n = 85) | | Girls (n = 51) | | Total (n = 136) | | Boys (n = 99) | | Girls (n = 33) | | Total (n = 132) | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Age | 10.3 | 1.4 | 10.3 | 1.4 | 10.3 | 1.4 | 10.2 | 1.8 | 9.9 | 1.2 | 10.1 | 1.7 |
| FSIQ | 115.8 | 12.5 | 114.2 | 11.3 | 115.2 | 12.0 | 111.1 | 12.4 | 106.9 | 12.7 | 110.0 | 12.6 |
| Total time (sec) | 78.4 | 17.3 | 79.5 | 14.6 | 78.8 | 16.3 | 85.8 | 17.6 | 83.3 | 16.0 | 85.2 | 17.2 |
| Total overflow | 7.0 | 5.2 | 5.6 | 4.5 | 6.5 | 5.0 | 8.4 | 5.7 | 7.6 | 5.6 | 8.2 | 5.7 |
| Total dysrhythmia | 3.8 | 2.0 | 3.4 | 2.1 | 3.6 | 2.1 | 5.1 | 2.5 | 4.7 | 2.9 | 5.0 | 2.6 |

ADHD = attention-deficit hyperactivity disorder; FSIQ = full scale IQ.

wrist while the child is walking on heels, toes, and sides of the feet. Awkward posturing of arms, hands, or body is also scored during stressed and tandem gaits. For timed movements, overflow is categorized by the proximity of the extraneous movement to the intended movement. Proximal overflow involves movement of a muscle group in close proximity to the intended movement, and also includes exaggerated movement of the intended body part (e.g., lifting at elbow rather than wrist during hand patting). Orofacial overflow involves movement of mouth, tongue, or facial muscles during hand or leg movements. Mirror overflow involves unintended contralateral movements of homologous muscles, often observed in distal limbs, which accompany voluntary movements.

Total dysrhythmia included the total number of timed motor examination trials in which the child failed to maintain steady rhythm for the duration of the task.

**Inhibitory control test.** Inhibitory control was also evaluated on a subset of this sample (n = 225) using a contralateral motor response test, which has been shown to be associated with motor overflow and ADHD.[3] Participants closed their eyes and were instructed to raise their right hand when touched on their left hand and raise their left hand when touched on their right hand (see Mostofsky et al.[3] for a more detailed description).

**Data analyses.** Data were examined using three multiple linear regression analyses, predicting each of the dependent variables (total time, total overflow, total dysrhythmia). In order to control for group differences in IQ, for regression analyses comparing ADHD and control groups, IQ was entered hierarchically in the first step, while age, sex, group, and the two- and three-way interactions were entered simultaneously in the second step. For all regression analyses, the continuous predictor variable (age) was centered by subtracting the mean age from each participant's age. Centering reduces the multicollinearity between predictors and interaction terms without altering the significance of the interaction or values of simple slopes.[17] When indicated, post hoc examination of the moderating effects of group or sex on age-related changes in PANESS performance was examined. Post hoc exploration of relationship between overflow and the inhibitory control measure (contralateral motor response test) was made using Pearson correlations.

## RESULTS

**Demographic information.** Demographic information for the sample is provided in table 1. There were no differences in mean age between boys and girls [$F(1,267) = 0.47$, $p = 0.49$], or between the ADHD and control groups [$F(1,267) = 1.10$, $p = 0.30$]. Boys and girls did not differ in IQ [$F(1,257) = 1.44$, $p = 0.23$]; however, controls group had higher IQ than the ADHD group [$F(1,257) = 11.40$, $p = 0.001$]. Thus, IQ was controlled statistically in subsequent regression analyses.

**PANESS.** For the main regression analysis, assumptions of linear regression were confirmed. The predictor variables were all normally distributed. Residuals for each of the predictor variables were consistent across values, showing homoscedasticity. Error terms were normally distributed and were without significant autocorrelation for main analyses. Means and standard deviations for boys and girls, and for ADHD and control groups on total time, total overflow, and total dysrhythmia, are presented in table 1.

For total time, after controlling for IQ, the overall model was supported ($p < 0.0001$, $R^2 = 0.368$), and without significant autocorrelation (Durbin-Watson = 1.75). Linear regression revealed effects for age ($p < 0.001$), time decreasing with age, and group ($p = 0.04$), with controls faster than children with ADHD. The main effect for sex and the two- and three-way interactions were not significant (table 2).

For overflow, after controlling for IQ, the overall model was supported ($p = 0.001$, $R^2 = 0.071$), and without significant autocorrelation (Durbin-Watson = 1.75). There was a three-way age × group × sex interaction ($p = 0.01$; see table 2). Regression analyses were subsequently performed separately for ADHD and control groups. Among controls, neither age ($p = 0.104$), sex ($p = 0.088$), nor the age × sex interaction ($p = 0.545$) were predictors of overflow. In contrast, among children with ADHD, there remained age ($p = 0.011$) and age × sex interaction ($p = 0.015$) effects. Given the age × sex interaction within children with ADHD, post hoc analyses of the simple slopes of regression lines for age were calculated separately for boys and girls with ADHD. For boys with ADHD, the slope for age-related reduction in overflow indicated overflow movements changed little from age 7 to 15 ($b = 0.06$, $t = 0.017$, $p = 0.866$). However, for girls with ADHD, the slope suggested overflow movements decreased with age ($b = -2.10$, $t = -2.862$, $p = 0.008$) (figure 1).

For dysrhythmia, after controlling for IQ, the overall model was supported ($p < 0.0001$, $R^2 = 0.119$), and without significant autocorrelation (Durbin-Watson = 1.74). There were effects for group ($p = 0.001$), with controls having less dysrhythmia than the ADHD group, and an age × group interaction ($p < 0.05$; see table 2). Regression analyses were subsequently performed separately for ADHD and control groups. Among controls, age ($p = 0.18$), sex ($p = 0.29$), and the age × sex interaction ($p = 0.70$) were not predictors of dysrhythmia. Within the ADHD group, age ($p = 0.002$) and the age × sex interaction ($p = 0.015$) remained predictors. Given our interest in sex differences within ADHD, exploratory post hoc analyses of the simple slopes of regression lines for age were calculated separately for boys and girls with ADHD. For boys with ADHD, the slope for age-related reduction in dysrhythmia indicated these movements decreased very little for boys ($b = -0.15$, $t = -1.07$, $p = 0.29$), though decreased with age for girls with ADHD ($b = -1.11$, $t = -2.940$, $p = 0.006$) (figure 2).

**Relationship of PANESS to inhibitory control.** The relationship between the performance-based mea-

**Table 2** Effects of age, sex, and group on the Physical and Neurologic Examination of Subtle Signs time and subtle signs

| Dependent variable | Step | Predictor entered | β | 95% CI for β | t | p |
|---|---|---|---|---|---|---|
| Total time | 1 | IQ | −0.12 | −0.29 to 0.04 | −1.46 | 0.147 |
| | 2 | Age | −5.91 | −8.57 to −3.24 | −4.37 | 0.000* |
| | | Sex | 1.94 | −1.78 to 5.67 | 1.03 | 0.306 |
| | | Group | 3.67 | 0.14 to 7.21 | 2.05 | 0.042* |
| | | Age × sex | −1.69 | −5.10 to 1.72 | −0.98 | 0.329 |
| | | Age × group | −0.89 | −5.59 to 3.82 | −0.37 | 0.712 |
| | | Age × sex × group | 2.57 | −2.83 to 7.97 | 0.94 | 0.349 |
| Overflow | 1 | IQ | −0.01 | −0.06 to 0.04 | −0.53 | 0.595 |
| | 2 | Age | −0.76 | −1.75 to 0.23 | −1.52 | 0.130 |
| | | Sex | 1.33 | −0.05 to 2.72 | 1.90 | 0.059 |
| | | Group | 1.08 | −0.22 to 2.39 | 1.63 | 0.104 |
| | | Age × sex | −0.40 | −1.66 to 0.86 | −0.63 | 0.532 |
| | | Age × group | −1.27 | −3.03 to 0.48 | −1.43 | 0.155 |
| | | Age × sex × group | 2.50 | 0.48 to 4.51 | 2.44 | 0.015* |
| Dysrhythmia | 1 | IQ | −0.03 | −0.05 to 0.00 | −2.15 | 0.032* |
| | 2 | Age | −0.27 | −0.71 to 0.18 | −1.18 | 0.238 |
| | | Sex | 0.51 | −0.10 to 1.13 | 1.64 | 0.102 |
| | | Group | 1.04 | 0.45 to 1.62 | 3.50 | 0.001* |
| | | Age × sex | 0.08 | −0.48 to 0.65 | 0.29 | 0.769 |
| | | Age × group | −0.80 | −1.58 to −0.02 | −2.03 | 0.044* |
| | | Age × sex × group | 0.80 | −0.09 to 1.70 | 1.76 | 0.079 |

*Significant.

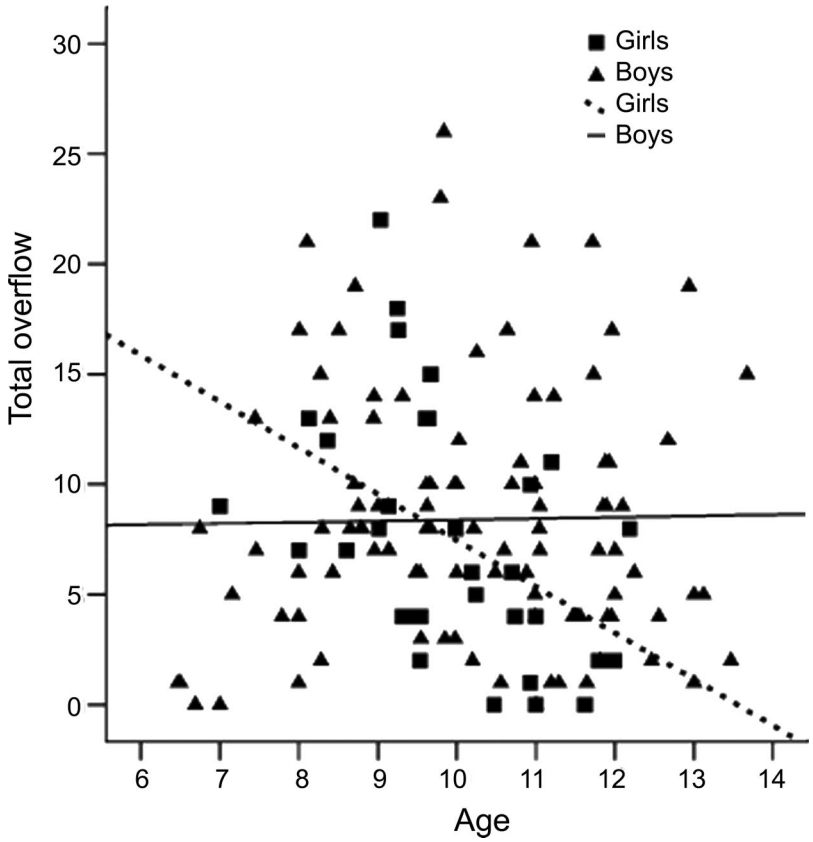
sure of motor inhibitory control and PANESS overflow was examined in a subset of the sample ($n = 225$) who had received both the PANESS and the contralateral motor response test. There was a significant correlation ($r = -0.30$, $p < 0.001$) between PANESS overflow and total score from the contralateral motor response test.

**DISCUSSION** The behavioral findings in the current study are consistent with previous studies using the PANESS, where speed of responding improves with age[5,14] and overflow[18] and dysrythmia[5] diminish over time in typically developing children. Among school-aged children, age-related improvements in motor speed are moderated by the presence of ADHD. Subtle signs are moderated by both sex and ADHD status. Girls with ADHD showed age-expected improvements in motor overflow and dysrhythmia, consistent with patterns observed in typically developing controls, whereas boys with ADHD did not improve with age. Current data also support previously established associations between overflow and difficulties with motor inhibition, further suggesting a link between overflow and motor inhibition.[3]

The current findings are consistent with multiple anatomic and functional MRI studies that have identified differences in brain development between children with ADHD and controls. These differences include abnormalities in regions important for motor control, such as frontal cortex,[19,20] premotor and motor regions,[21] and interconnected subcortical structures.[22,23] The current results also parallel Garvey and colleagues'[6] findings where the ipsilateral silent period latency, related to the transcallosal inhibition considered necessary for suppressing motor overflow, was found to improve with age in male controls but not in boys with ADHD,[6] suggesting a delay in the development of interhemispheric connections important for transcallosal inhibition in boys with ADHD. The present results are also consistent with neuroimaging findings showing decreased primary motor cortex activation in children with ADHD when engaging in a simple finger sequencing task.[24] Though these studies provide an explanation for the age-inappropriate subtle signs observed in boys with ADHD,[25] they provide little insight into the relative absence of these deficits among girls with ADHD, as most of these studies of ADHD were completed using samples that were either exclusively or predominantly male.

Among children with ADHD, sex-related differences are consistent with prior research in controls.

**Figure 1** Scatterplot of total overflow for children with attention-deficit hyperactivity disorder




For example, Larson and colleagues found that among control children directly matched on age, all instances of sex-related differences in motor skill (speed, overflow, dysrhythmia) favored girls.[5] Longitudinal neuroanatomic studies have shown that brain regions considered important in motor control reach maximum size at least 1 year earlier in girls than in boys.[9] Given the earlier maturation of these indicated brain areas in girls, it may be that the neurologic anomalies responsible for motor impairment in boys with ADHD are either absent or more subtle in school-aged girls with ADHD.

Several additional factors may underlie the observed sex-related patterns of motor skill development observed in the ADHD group. First, the lack of sex-related differences on the timed variable may be due to lower sensitivity to differences between boys and girls or the influence of large differences between boys with ADHD and controls on group effects. With regard to subtle signs, girls may "outgrow" their motor anomalies prior to age 7. Further, girls typically present with more inattentive symptoms of ADHD, while boys show more hyperactive/impulsive symptoms.[26] Motor examination may be more sensitive to detecting abnormalities associated with hyperactivity, which reflect problems with control of unwanted movements and are more strongly tied to motor control, rather than those driving the inattentive subtype.[27] Finally, motor assessment may be less sensitive among girls, compared with measures of affective control, which have been shown to be persistent areas of deficit in girls with ADHD.[26] Regardless, the pattern of findings suggests that when considering developmental patterns of executive and motor control in ADHD, boys and girls should be studied separately and at younger ages for a fuller understanding of the female-specific patterns of deficit.

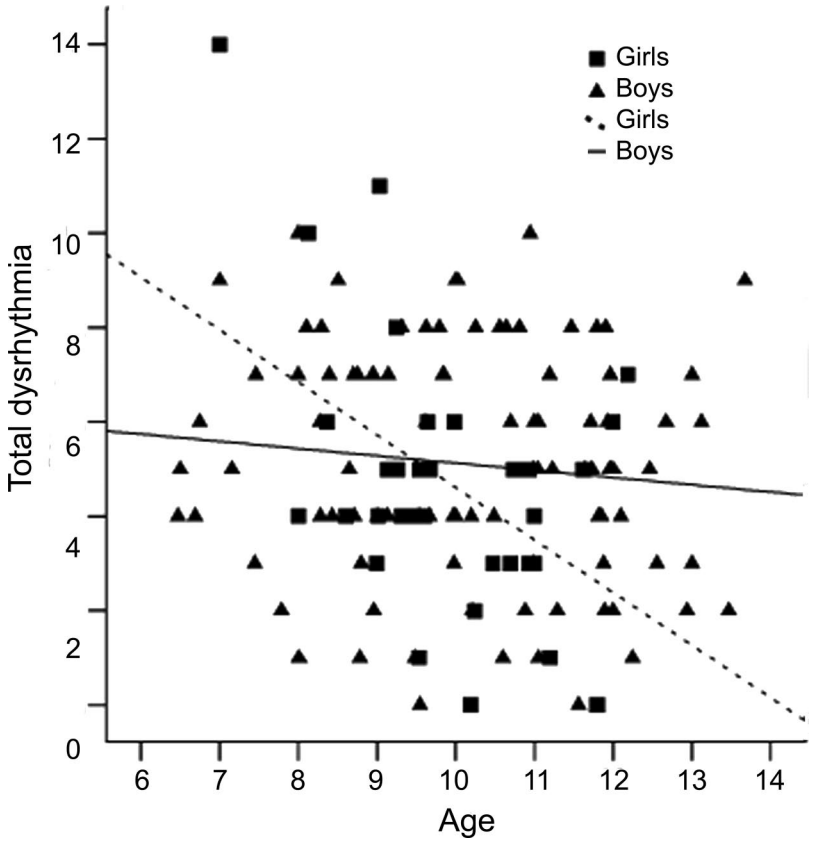
Motor and executive control systems develop in a parallel manner, such that each system is dependent upon the functional integrity and maturation of related brain regions, suggesting a shared neural circuitry including frontostriatal systems and cerebellum.[1] The systems that support motor and executive control have a protracted period of development[28] and are vulnerable to disruption via a variety of etiologies, which is likely why so many children with neurodevelopmental disorders present with motor and executive dysfunction.[29] Therefore, assessment of motor function can be critical to understanding both the biologic substrates and cognitive phenotypes associated with neurodevelopmental disorders such as ADHD.[3]

The current study highlights the clinical utility of the revised PANESS as a measure sensitive to brain-related changes associated with typical and atypical development. Given the inconsistency of findings regarding ADHD-related deficits on cognitive measures of behavioral control,[30] and especially among intellectually higher functioning children,[31] assessment of motor subtle signs may provide unique information regarding the neurobehavioral status of these children.

Motor examinations, such as the PANESS, which highlight both speed and subtle signs, may be sensitive to anomalous neurologic development, even in the absence of "cognitive" neuropsychological findings.[30] Such assessment may be especially useful for higher functioning children with ADHD, who may perform normally on other neuropsychological measures.[32] Nevertheless, even in the context of "normal" motor examinations, girls with ADHD remain at risk for functional impairments.[26]

The current study benefited from the large sample size, the contemporaneous collection of data on boys and girls, the use of a standardized motor examination, and the inclusion of an ADHD sample that was carefully screened for comorbid conditions. Nevertheless, while screening for comorbid disorders is a strength, the results may be less generalizable to clinical samples which typically have multiple comorbidities. There were also several limitations of the current study. First, the present sample was cross sectional rather than longitudinal. Longitudinal investigations may further clarify the nature of motor development in boys and girls with and without

**Figure 2** Scatterplot of total dysrhythmia for children with attention-deficit hyperactivity disorder




ADHD, particularly if younger samples are included. Second, because the data were collected based on *DSM-III-R* and *DSM-IV* diagnoses of ADHD, we included children with all ADHD subtypes, and did not directly evaluate age- and sex-related changes specific to ADHD subtypes, as delineated in the *DSM-IV*. Future research should continue to examine the trajectories of ADHD subtypes in boys and girls, with concomitant examination of motor development as a potential marker for neurodevelopmental maturity. Additionally, the current study focused primarily on age-related changes, but did not account for variations in sexual maturation using a validated measure. Also, given the noted links between motor performance and brain development, future studies should seek to examine age- (taking into account sexual maturation) and sex-specific imaging correlates of motor performance in samples in which differences in trajectory of growth between the sexes can be studied directly.

*Received April 7, 2008. Accepted in final form July 31, 2008.*

## REFERENCES


1. Diamond A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. Child Dev 2000;71:44–56.
2. Hoy KE, Fitzgerald PB, Bradshaw JL, Armatas CA, Georgiou-Karistianis N. Investigating the cortical origins of motor overflow. Brain Res Brain Res Rev 2004;46:315–327.
3. Mostofsky SH, Newschaffer CJ, Denckla MB. Overflow movements predict impaired response inhibition in children with ADHD. Percept Mot Skills 2003;97:1315–1331.
4. Lazarus JA, Todor JI. Age differences in the magnitude of associated movement. Dev Med Child Neurol 1987;29:726–733.
5. Larson J, Mostofsky SH, Goldberg MC, Cutting LE, Denckla MB, Mahone EM. Effects of gender and age on motor exam in developing children. Dev Neuropsychol 2007:543–562.
6. Garvey MA, Barker CA, Bartko JJ, et al. The ipsilateral silent period in boys with attention-deficit/hyperactivity disorder. Clin Neurophysiol 2005;116:1889–1896.
7. Mayston MJ, Harrison LM, Stephens JA. A neurophysiological study of mirror movements in adults and children. Ann Neurol 1999;45:583–594.
8. Roeder MB, Mahone EM, Larson JG, et al. Left-right differences on timed motor examination in children. Child Neuropsychol 2007:1–14.
9. Lenroot RK, Gogtay N, Greenstein DK, et al. Sexual dimorphism of brain developmental trajectories during childhood and adolescence. Neuroimage 2007;36:1065–1073.
10. Reich W. Diagnostic interview for children and adolescents (DICA). J Am Acad Child Adolesc Psychiatry 2000;39:59–66.
11. DuPaul GJ, Power TJ, Anastopoulos AD, Reid R. ADHD Rating Scale–IV. New York: Guilford Press; 1998.
12. Conners CK. Conners' Rating Scales: Revised. North Tonawanda, NY: Multi-Health Systems Inc; 1997.
13. Denckla MB. Revised neurological examination for subtle signs. Psychopharmacol Bull 1985;21:773–779.
14. Denckla MB. Development of motor co-ordination in normal children. Dev Med Child Neurol 1974;16:729–741.
15. Holden EW, Tarnowski KJ, Prinz RJ. Reliability of neurological soft signs in children: reevaluation of the PANESS. J Abnorm Child Psychol 1982;10:163–172.
16. Vitiello B, Ricciuti AJ, Stoff DM, Behar D, Denckla MB. Reliability of subtle (soft) neurological signs in children. J Am Acad Child Adolesc Psychiatry 1989;28:749–753.
17. Holmbeck GN, Li ST, Schurman JV, Friedman D, Coakley RM. Collecting and managing multisource and multimethod data in studies of pediatric populations. J Pediatr Psychol 2002;27:5–18.
18. Garvey MA, Ziemann U, Bartko JJ, Denckla MB, Barker CA, Wassermann EM. Cortical correlates of neuromotor development in healthy children. Clin Neurophysiol 2003;114:1662–1670.
19. Castellanos FX, Lee PP, Sharp W, et al. Developmental trajectories of brain volume abnormalities in children and adolescents with attention-deficit/hyperactivity disorder. JAMA 2002;288:1740–1748.
20. Mostofsky SH, Cooper KL, Kates WR, Denckla MB, Kaufmann WE. Smaller prefrontal and premotor volumes in boys with ADHD. Biol Psychiatry 2002;52:785–794.
21. Mostofsky SH, Dubey P, Jerath VK, Jansiewicz EM, Goldberg MC, Denckla MB. Developmental dyspraxia is

not limited to imitation in children with autism spectrum disorders. J Int Neuropsychol Soc 2006;12:314–326.
22. Mostofsky SH, Reiss AL, Lockhart P, Denckla MB. Evaluation of cerebellar size in attention deficit hyperactivity disorder. J Child Neurol 1998;13:434–439.
23. Wellington TM, Semrud-Clikeman M, Gregory AL, Murphy JM, Lancaster JL. Magnetic resonance imaging volumetric analysis of the putamen in children with ADHD: combined type versus control. J Atten Disord 2006;10:171–180.
24. Mostofsky SH, Rimrodt SL, Schafer JG, et al. Atypical motor and sensory cortex activation in attention-deficit/hyperactivity disorder: a functional magnetic resonance imaging study of simple sequential finger tapping. Biol Psychiatry 2006;59:48–56.
25. Shaw P, Eckstrand K, Sharp W, et al. Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. Proc Natl Acad Sci USA 2007;104:19649–19654.
26. Hinshaw SP, Owens EB, Sami N, Fargeon S. Prospective follow-up of girls with attention deficit/hyperactivity disorder into adolescence: Evidence for continuing cross-domain impairment. J Consult Clin Psychol 2006;74:489–499.
27. Castellanos FX, Sonuga-Barke EJ, Milham MP, Tannock R. Characterizing cognition in ADHD: beyond executive dysfunction. Trends Cogn Sci 2006;10:117–123.
28. Thompson PM, Sowell ER, Gogtay N, et al. Structural MRI and brain development. Int Rev Neurobiol 2005;67:285–323.
29. Mahone EM, Slomine BS. Managing dysexecutive disorders. In: Hunter S, Donders J, eds. Pediatric Neuropsychological Intervention. Cambridge, UK: Cambridge University Press; 2007: 287–313.
30. Wodka EL, Mostofsky SH, Prahme C, Larson JCG, Denckla MB, Mahone EM. Process examination of executive function in ADHD: gender and subtype effects. Clin Neuropsychol 2008 (in press).
31. Mahone EM, Cirino PT, Cutting LE, et al. Validity of the Behavior Rating Inventory of Executive Function in children with ADHD and/or Tourette syndrome. Arch Clin Neuropsychol 2002;17:643–662.
32. Mahone EM, Hagelthorn KM, Cutting LE, et al. Effects of IQ on executive function measures in children with ADHD. Child Neuropsychol 2002;8:52–65.